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TESTS OF VEHICLE AND IMPLEMENT WOODS.

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TESTS OF VEHICLE AND IMPLEMENT WOODS.

From the time that agricultural implements were first made only a few woods have been thought suitable for their manufacture. For years the maker of vehicles and implements has made the point that his wares were constructed only of certain kinds of wood, and the consumer has in consequence been led to believe that these woods, and only these, will serve the purpose; yet to-day, with the rapid decrease in their supply, the manufacturer is confronted with the necessity of using them with the greatest economy and of finding other kinds which he can, whenever necessary, use in their place.

The tests the results of which are given in this circular were made to obtain a better knowledge of the mechanical properties of the woods at present used in the manufacture of vehicles and implements and of those which might be substituted for them. Such knowledge should also bring about a closer utilization of material and lead to the establishment of more correct grading rules. The tests were conducted at Lafayette, Ind., in cooperation with Purdue University, under the general supervision of Dr. W. K. Hatt, and were made possible through the cooperation of the National Wagon Manufacturers' Association of America, the Carriage Builders' National Association, and the National Hickory Association.

WOODS USED.

The uses of wood in the vehicle and implement industries may be considered under three heads—

(1) For light vehicles: Buggies, carts, automobiles, spring wagons, etc.

(2) For heavy vehicles: Farm wagons, drays, sleds, etc.

(3) For implements: Grain tanks, thrashers, plows, harrows, cultivators, binders, headers, corn cutters, corn shredders, hay rakes, tedders, clover hullers, etc.

LIGHT VEHICLES.

In buggy bodies the preferred woods for panel work are poplar and cottonwood and for framework ash. Many substitutes have been used because of the scarcity of poplar and ash. Red gum, bass-

wood, silver maple, and buckeye are used to some extent for panels, and maple, oak, beech, red gum, rock elm, white elm, hackberry, butternut, and pecan are used in the framework. Of the new woods, maple and red gum are used to the greatest extent. Sheet iron has been tried for panels, but it holds paint so poorly and dents so easily that it is unsatisfactory. Red gum is much used for buggy bottoms and for all parts of sleighs.

Rock elm has an elastic toughness coupled with a certain degree of hardness that has given it precedence in hub manufacture. These qualities allow the spokes to "settle" in the hub so that they form a close union without crushing the fibers. Black locust has this characteristic to a lesser degree, and persimmon, black birch, and dogwood are fairly satisfactory for hub manufacture.

For buggy poles, shafts, spokes, and in the gear work, except for axle caps, for which maple has been largely substituted, hickory is practically the only wood used.

HEAVY VEHICLES.

The following is a list of parts and the woods commonly used in the manufacture of heavy vehicles:

Box boards	Yellow poplar, cottonwood, red gum, tupelo.
Box cleats	Yellow poplar, cottonwood, rock elm.
Box beds	Longleaf pine, birch, oak.
Bed cleats	Oak, rock elm.
Axles	Hickory, maple.
Bolsters	Oak, hickory.
Sand boards	Oak, hickory.
Poles	Oak.
Brake bars	Oak, rock elm.
Reaches	Oak.
Standards	Oak, rock elm, hickory.
Hounds	Oak, rock elm.
Spokes	Oak.
Rims and fellies	Oak, Osage orange (southern trade).
Hubs	White, red, and willow oak, black and yellow birch.
Doubletrees	Hickory, rock elm, oak.
Singletrees	Hickory, rock elm.
Neckyokes	Hickory, rock elm.

A wood suitable for wagon-box boards is primarily one which does not warp nor split and is easily worked. The quality of resistance to abrasion is of importance, but durability is not considered. For box boards, white pine, when plentiful, was used almost exclusively; but yellow poplar is now the favorite, though cottonwood is largely used, and much of it is sold as poplar. Red gum, Douglas fir, cypress, western yellow pine, western spruce, and redwood have been used to a limited extent. These woods have answered the requirements fully where attention was given to overcoming small difficulties

in handling. One objection to Douglas fir is that when passed through planers the softer and more spongy springwood portion of the annual rings is torn out, which leaves the summerwood portion raised and gives the surface a ribbed appearance that increases the difficulty of getting a good finish. This disadvantage may be obviated, however, by increasing the speed of the planing machine and decreasing the feed.

The relative merits of maple and hickory for axle manufacture have been a matter of contention for years. Both woods are extensively employed, though maple finds greater use in the northern trade, while the southern trade prefers hickory. Endeavors to substitute steel for wood in axle construction have met with disfavor, since steel lacks the resilience of wood; the steel axle is described as "dead," the wood axle as "live."

For bolsters, longleaf pine has been put upon the market as a substitute for oak, and has given satisfaction, though a coniferous wood as a rule will not hold the standards in place as well as a hardwood, because the fibers crush more easily.

White oak and white ash were used formerly for poles, but the increase in price of ash has led to the general use of oak, supplemented to some extent by Douglas fir and longleaf pine. In general the white and red oaks are now used indiscriminately and little choice is made between the two, except in special orders for select stock.

The excessive checking, coupled with the high price of white oak, has led to the substitution of willow oak, red oak, and black and yellow birch for hubs. Birch hubs give the best results when they are shipped to the manufacturer in winter. Put into the warehouse while frozen, they can dry out gradually during cold weather, so that by the time they are sent to the dry house they are already comparatively dry, and molding has been prevented.

IMPLEMENTS.

Implement manufacture permits the use of many kinds of wood. There are implements in which almost any kind of softwood can be used for panel work and any kind of hardwood for sill or frame work; so longleaf pine has, to a great extent, replaced oak in implement manufacture.

Red gum and cottonwood are largely used for panels; the former is also used in combination with western spruce, pine, or fir, for narrow strip work, in places where it is liable to warp. In flaring grain tanks the side boards may be made of Douglas fir, western spruce, pine, red gum, or western hemlock, and the beds of longleaf pine, western hemlock, or Douglas fir. In these tanks it is possible to

use a wood which has some tendency to warp, as the four or six knees which support the flaring sides hold them in place.

In wheat and corn drills and similar implements ash, maple, or oak is generally used for framework. Cottonwood, gum, poplar, Douglas fir, spruce, and western pine are used for panel work. Ash, rock elm, and oak are used for spokes and rims, in combination with a metal hub. For implement poles longleaf pine and Douglas fir have given most satisfaction. Throughout the vehicle and implement industries there is a marked and increasing tendency to use western coniferous woods.

LABORATORY TESTS.

The value of different woods for vehicle and implement parts was investigated by laboratory tests of typical samples. The material for the tests was contributed in its finished form by manufacturers, and the conditions of the test were made to conform as far as possible to the conditions that would occur in actual service. The following is a list of the material upon which the tests were made:

Hickory buggy spokes.
Hickory and red-oak buggy shafts.
Hickory and maple wagon axles.
Oak, southern pine, and Douglas fir wagon poles.
Douglas fir and southern pine cultivator poles.

TESTS ON BUGGY SPOKES.

The object was to test the correctness of the present system of grading hickory buggy spokes and to ascertain the relative strength and toughness of red and of white spokes.

The material tested consisted of 500 1-inch hickory buggy spokes. The spokes were graded at the factory by an experienced foreman, and each grade packed separately. The different grades and the number of spokes in each, as graded at the factory in the order of their recognized commercial value, were as follows:

Grade.	Number of spokes.
A-white	45
B-white	45
C-white	45
C-red	45
C-mixed	45
D-white	45
D-red	45
D-mixed	45
E-white	45
E-red	45
Culls	50

The method of testing spokes is shown in figure 1. The spokes were compressed parallel to grain and the force applied to the rim end of the spoke through the movable head of the testing machine.

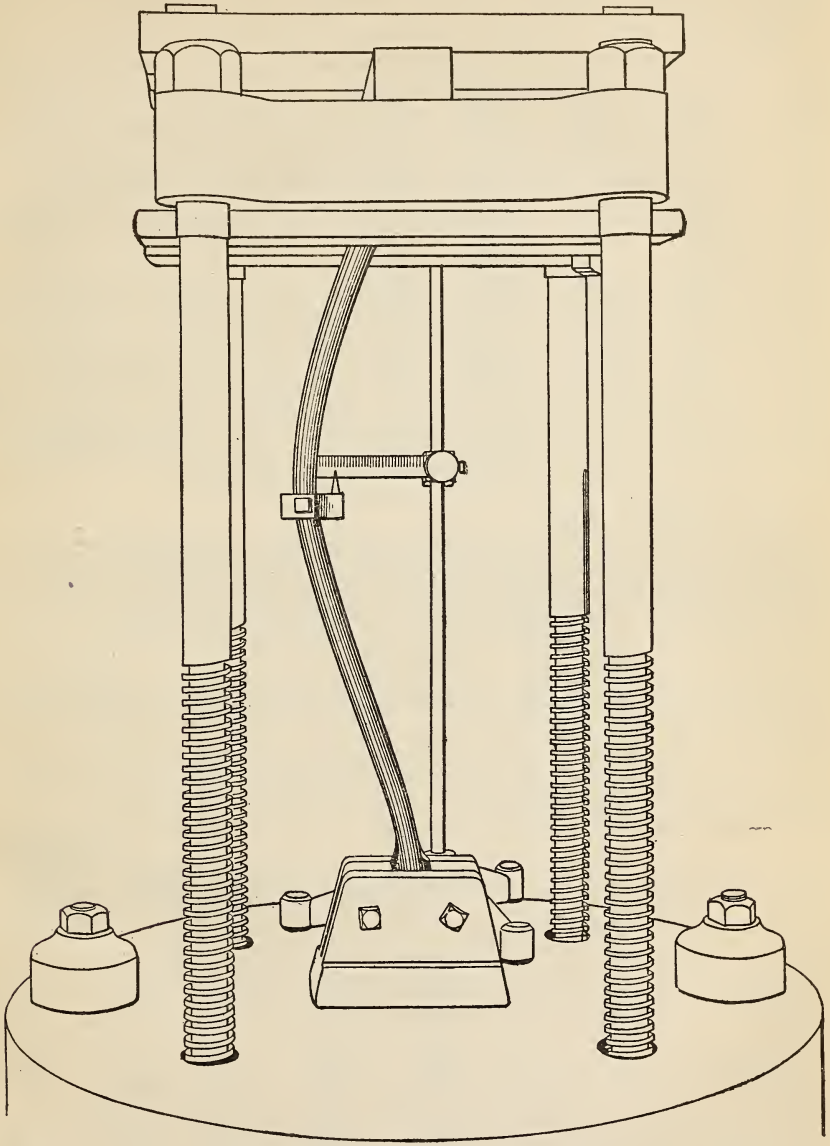

FIG. 1.—Method of testing buggy spokes.

The spokes were cut to a length of 21 inches, the length used in the most common size of wheel. The regulation tenon was cut on the rim end, and this tenon was inserted in a hole in an iron block

clamped to the movable head of the testing machine. The heel of the spoke fitted into a second iron block resting on the platform of the machine. With the spoke vertically placed in the machine, it represented a column with the rim and hub ends held in the same manner as in a wheel. The amount of bending or transverse deflection at the center was shown by a pointer attached to the spoke, and arranged to move over a horizontal graduated scale. During the test the load at the first visible failure and the maximum load were noted, together with the corresponding deflections at the center, and in each case the test was continued until the spoke had reached a deflection of 2 inches at the center. All spokes were thus subjected to the same conditions.

The factor representing the value of a spoke should include both strength and toughness. The greatest load held up by a spoke is a measure of its strength, and the amount of bending in a spoke when the first crack occurs is a measure of its toughness. The product of these two quantities gives a factor representing both strength and toughness. It is called the resilience factor. The various quantities measured and computed in the tests are as follows:

Weight of spoke in grams.

Maximum load in pounds, i. e., greatest load held up by the spoke.

Deflection in inches at maximum load and at first failure, i. e., amount of bending at center under maximum load and at time of first failure.

Resilience factor, i. e., maximum load × deflection at first failure.

RESULTS.

Table 1 gives the results of the tests with reference to the different grades.

TABLE 1.—*Tests on hickory buggy spokes.*

[One-inch spoke; length 21 inches.]

Grade.	Weight.	Maximum load.	Deflection at maximum load.	Deflection at first failure.	Resilience factor (maximum load multiplied by deflection at first failure).
	Grams.	*Pounds.*	*Inches.*	*Inches.*	
A-white:					
Average	177.5	3,899	0.28	1.22	4,760
Maximum	190.3	5,005	.50	1.75	8,080
Minimum	165.5	2,750	.10	.85	3,270
B-white:					
Average	164.5	3,332	.25	1.31	4,360
Maximum	182.5	4,780	.52	2.00	6,750
Minimum	146.0	1,615	.04	.72	2,740
C-white:					
Average	150.5	2,873	.29	1.22	3,500
Maximum	182.0	4,220	.46	1.75	6,050
Minimum	119.3	1,720	.07	.75	1,875
C-red:					
Average	157.2	3,080	.28	1.36	4,190
Maximum	173.3	4,525	.51	2.00	6,920
Minimum	144.4	1,835	.08	.80	2,150
C-mixed:					
Average	155.5	3,102	.25	1.27	3,940
Maximum	186.0	4,095	.44	2.00	8,710
Minimum	132.0	2,110	.05	.75	2,310

TABLE 1.—*Tests on hickory buggy spokes*—Continued.

Grade.	Weight.	Maximum load.	Deflection at maximum load.	Deflection at first failure.	Resilience factor (maximum load multiplied by deflection at first failure).
D-white:	*Grams.*	*Pounds.*	*Inches.*	*Inches*	
Average	144.2	2,815	0.28	1.13	3,180
Maximum	176.6	3,835	.55	1.75	5,360
Minimum	118.2	2,025	(a)	.65	2,045
D-red:					
Average	148.6	3,235	.29	1.25	4,050
Maximum	174.7	4,950	.66	2.00	5,620
Minimum	131.1	2,010	.10	.40	1,110
D-mixed:					
Average	145.2	3,171	.27	1.24	3,930
Maximum	166.2	4,250	.60	1.90	6,540
Minimum	112.8	2,065	.02	.70	2,000
E-white:					
Average	147.8	2,985	.25	1.13	3,370
Maximum	174.9	4,180	.50	2.00	5,920
Minimum	124.7	1,400	.04	.75	1,680
E-red:					
Average	146.1	3,009	.24	1.08	3,250
Maximum	180.2	4,500	.45	1.85	7,080
Minimum	106.5	2,050	.05	.50	1,600
Culls:					
Average	156.8	2,738	.27	1.18	3,230
Maximum	191.4	4,025	.50	2.00	6,200
Minimum	116.5	1,775	.10	.33	805

[a] Reading not obtained.

From this table it will be seen that the average weight and the average resilience factor of the A-white spokes were both considerably higher than in the other grades. A wide range between the maximum and minimum value for the resilience factor in any grade is noticeable, showing that the quality of the spokes varied in each grade. The C-red spokes have a higher resilience factor than either the C-mixed or C-white. In the same way the D-red spokes have a higher resilience factor than the D-mixed or D-white; D-red ranks ahead of C-mixed and C-white; E-red and E-white rank nearly equal, though E-white has a slightly higher resilience factor than E-red.

Figure 2 shows 10 grade-A spokes after failure; 5 typical spokes that have a high resilience factor and 5 with a low resilience factor are represented in this figure. Beneath each spoke is given the resilience factor, weight, and the strength or maximum load held up by the spoke. It can be seen that there is wide range in the resilience factors.

In investigating the relation between weight and resilience factor, only clear spokes were used. This was done in order to eliminate the influence of defects such as iron streaks, bird pecks, knots, cross-grain, and wormholes. About 230 spokes were used. The weight and resilience factor of each of these spokes is plotted in figure 3.

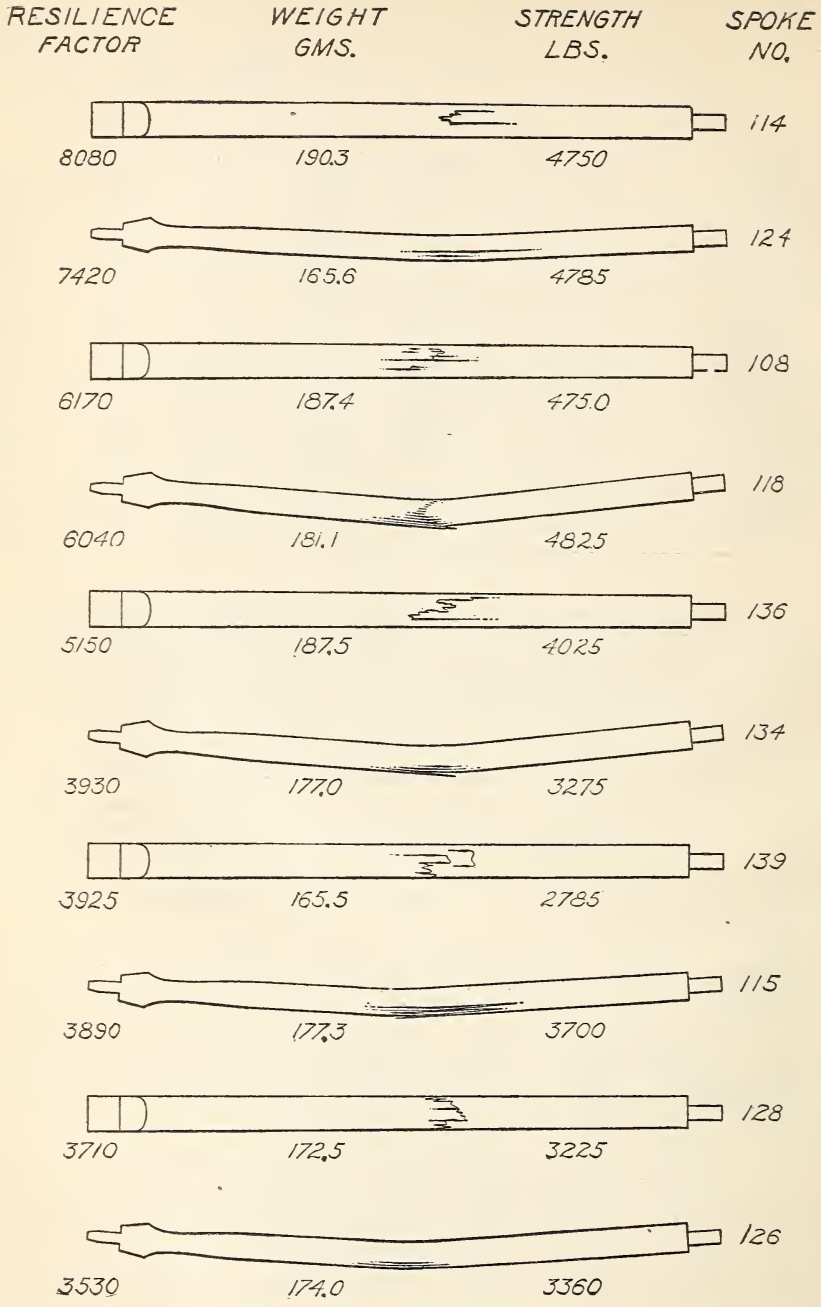

FIG. 2.—Hickory spokes after test, grade A.

[Cir. 142]

In this chart the weight of the spokes is shown by the horizontal scale, and the resilience factor by the vertical scale. The results of the tests, as plotted, are divided into three classes—red, white, and mixed color, distinguished on the diagram by different marks. The average points through which the heavy lines are drawn were obtained by grouping points lying between certain limits of weight. Figure 3 eliminates other factors than that of color, and shows that in the case of clear spokes the resilience factor increases directly with the weight in a fairly uniform manner. The diagram also shows

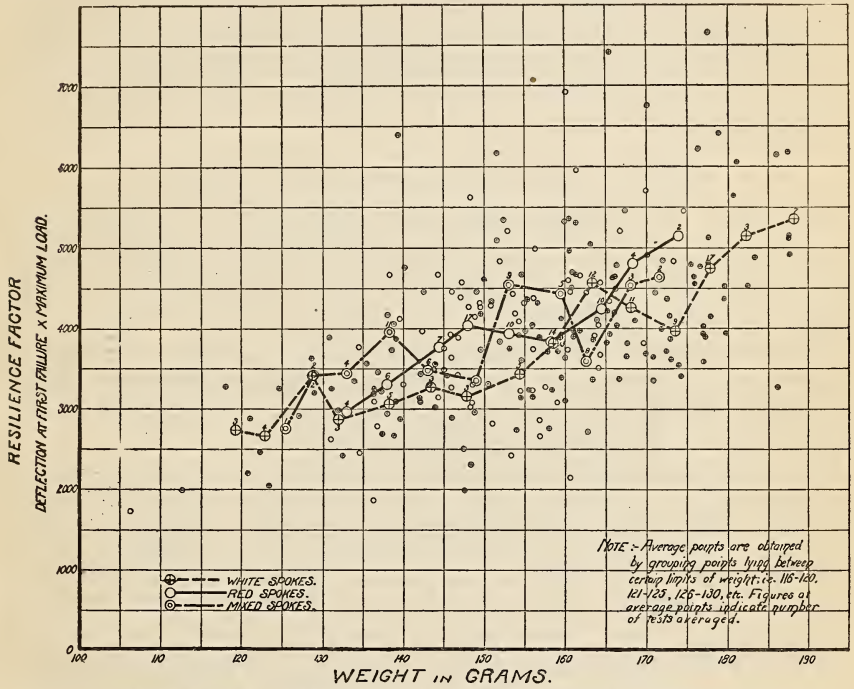

FIG. 3.—Spoke-test chart, showing relation between resilience factor and weight in clear spokes.

that weight for weight the red and mixed spokes have as great a resilience factor as the white spokes—that is, the red spokes and the white spokes of equal weight are equal in mechanical value.

Defects in spokes commonly include iron streaks, bird pecks, cross-grain, knots, and wormholes. A spoke containing a wormhole is dangerous, as it is impossible to tell to what an extent the spoke has been bored on the inside. Iron streaks are supposed to be caused by the infiltration of foreign coloring matter through bird pecks. Iron streaks and bird pecks, when they show only slightly, apparently do not affect the mechanical qualities of a spoke. They are not gener-

ally found in the heaviest spokes, but among those of medium or light weight.

Spokes failing from crossgrain generally break into two pieces.

Defects, such as knots, have greater weakening effect when near the center than when near the ends. Figures 4 and 5 show the results of defects near the center and defects near the ends. The lower resilience factor in the spokes with defects near the center is noticeable.

The spoke tests definitely show three things: (1) That the present system of grading buggy spokes does not correspond to their strength and toughness, (2) that the factor denoting the strength and toughness of clear spokes varies directly with the weight, and (3) that red, white, or mixed spokes of equal weight have practically the same resilience factor.

TESTS ON OAK AND HICKORY BUGGY SHAFTS.

The object of the shaft tests was to determine the relative mechanical properties of hickory shafts graded as XX, which is a third grade, and shafts made of red oak, to show the possibilities of the latter in shaft construction.

The shafts were of the buggy pattern, $1\frac{3}{8}$ by $1\frac{7}{8}$ inches. The stock was secured in Mississippi, about 100 miles south of Memphis, Tenn. The material was kiln-dried, steamed, and bent. Ninety-two shafts were tested—46 XX hickory and 46 red oak.

The conditions under which shafts are broken in actual service are so varied that no attempt was made to reproduce any one of them exactly. The rigging for testing the shafts was arranged to hold the butt end of the shaft so that the main part projected horizontally. A vertical force was then applied near the point, and the shaft bent upward. The amount of bending or deflection near the point and the corresponding force required to produce this deflection were noted at regular intervals. The tests were continued after maximum load until there was less than 20 pounds pull on the shaft, or until the shaft came in contact with the head of the testing machine.

RESULTS.

The weights of the two sets of shafts when dry were about the same; but the oak shafts, as they were tested, were slightly lighter than the hickory and contained 1.1 per cent less moisture. The oak shafts closely approximated the hickory in strength values, but at the maximum load had $7\frac{1}{2}$ per cent less deflection. In only one quality was the oak decidedly inferior to the hickory—the ability to sustain a load after failure. Thirty of the 46 oak shafts were broken in two, and only 9 sustained more than 20 pounds load at the end of the

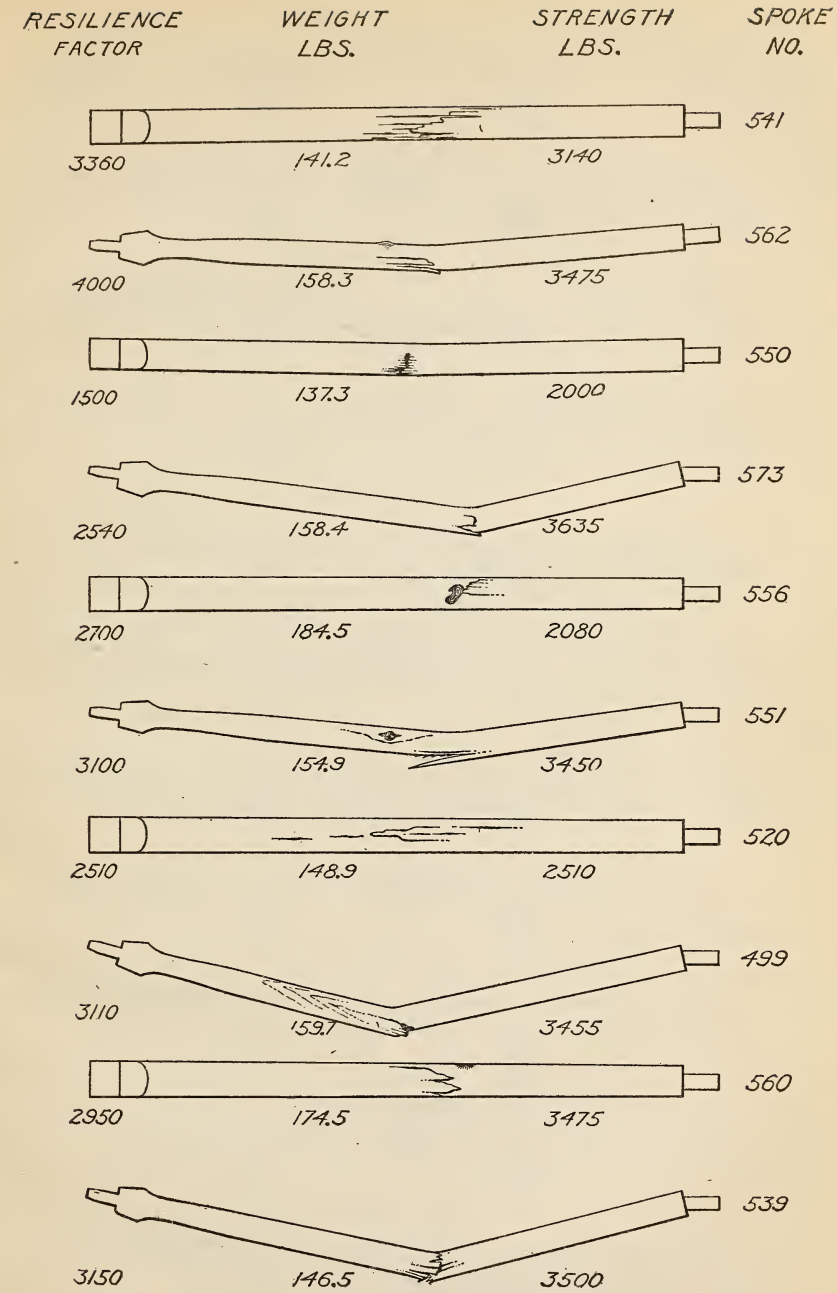

FIG. 4.—Results of tests on defective spokes; defects near center.

[Cir. 142]

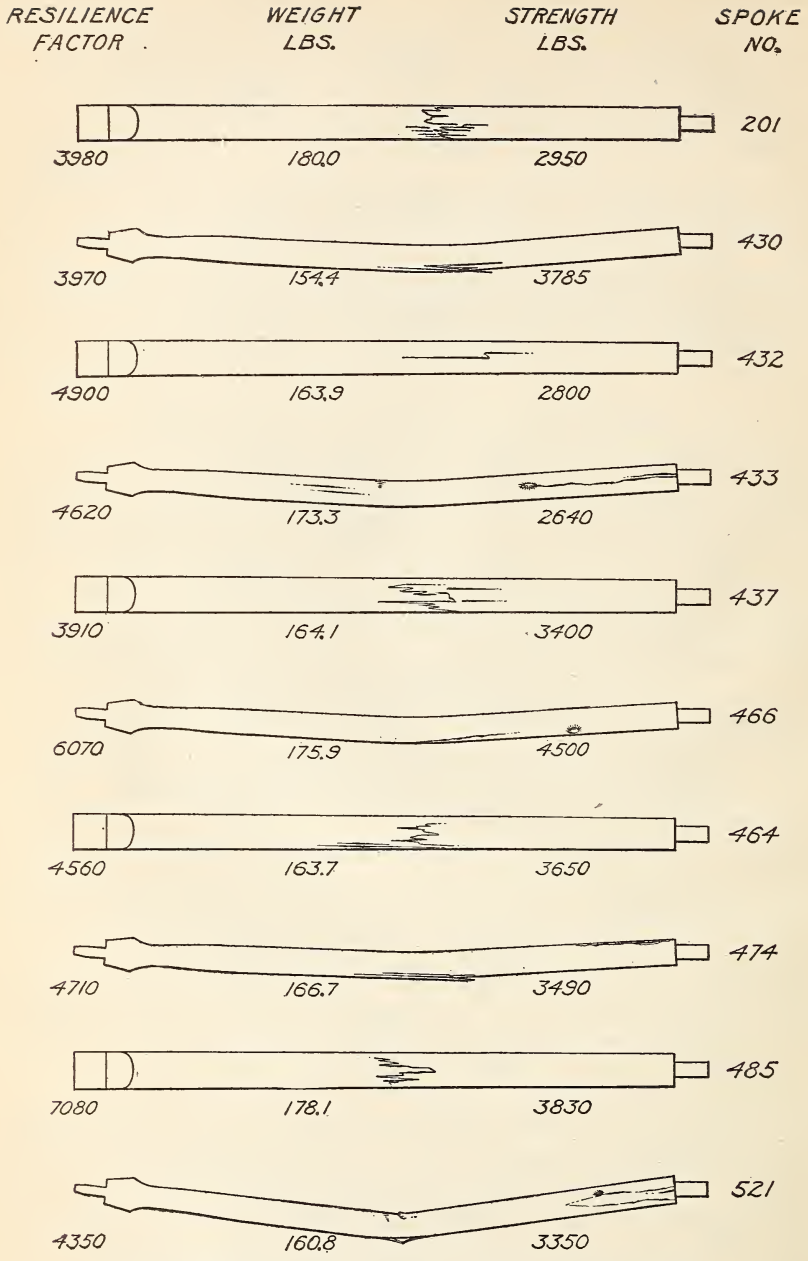

FIG. 5.—Results of tests on defective spokes; defects near ends.

[Cir. 142]

tests; only 14 of the hickory shafts were broken in two, and 24, or more than half of them, sustained more than 20 pounds at the end of the test. The drier condition of the oak shafts tended to increase their strength in comparison with the hickory and to decrease the work after the maximum load. Had the oak been as wet as the hickory it would not have appeared to as good advantage as regards strength, but would have shown more ability to sustain a load after failure. Had the two sets of shafts been equal in moisture content the averages of the different factors would have been closer, but the oak would still have had the same points of superiority, though the degree of difference would have been less. A comparison of the maximum and minimum values given in Table 2 shows that the oak shafts were of much more uniform quality than the hickory, in spite of the fact that many of the complete failures in the oak shafts were due to cross or spiral grained pieces that would be eliminated by careful inspection of market material.

While these shaft tests are valuable as showing the possibility of using red oak instead of XX hickory, they can not be taken as conclusive for a number of reasons: First, the tests were too few to give sufficiently definite results. Second, the oak shafts were not as carefully selected as commercial stock should be; straight-grained material would be to the advantage of oak in comparison with the lower grade of hickory. Third, the grading of the hickory down to the XX quality was based largely on the red color, which, as shown by the spoke tests, is no criterion of degree of strength; on a strength basis some of the red hickory shafts might have belonged in a higher grade.

TESTS ON MAPLE AND HICKORY WAGON AXLES.

The object of the tests on maple and hickory wagon axles was to ascertain the relative strength of maple and hickory in the form of wagon axles, and to compare the efficiency of several styles of axle reinforcement.

The material consisted of 48 rear axles of the common farm wagon design—24 of hickory and 24 of maple. Three styles of construction were represented for each species—thimble skein, thimble skein trussed, and long-sleeve skein trussed. The axles selected were as nearly uniform in quality of wood as could be secured, and were representative of average seasoned stock.

Figure 6 shows the method of testing. The axles, with hubs placed on each skein, were mounted on two I-beams, which rested upon the platform of a testing machine. Loads were applied by the testing machine at the two hounds by means of a straining beam attached to the movable head of the machine. Heavy car springs were placed

between the I-beams and the platform of the testing machine, so as to make the load follow the axles after failure occurred, to reproduce the continuous gravity action that would occur in a failure under service conditions. Rollers were used under all bearing plates in order to insure freedom in horizontal movement at the bearing points. The load was applied continuously until the maximum load was passed.

Tables 3, 4, 5, and 6 in the Appendix give the results of the tests.

An adjusted set of results was calculated because the maple axles had a slightly larger cross section than the hickory. In the table

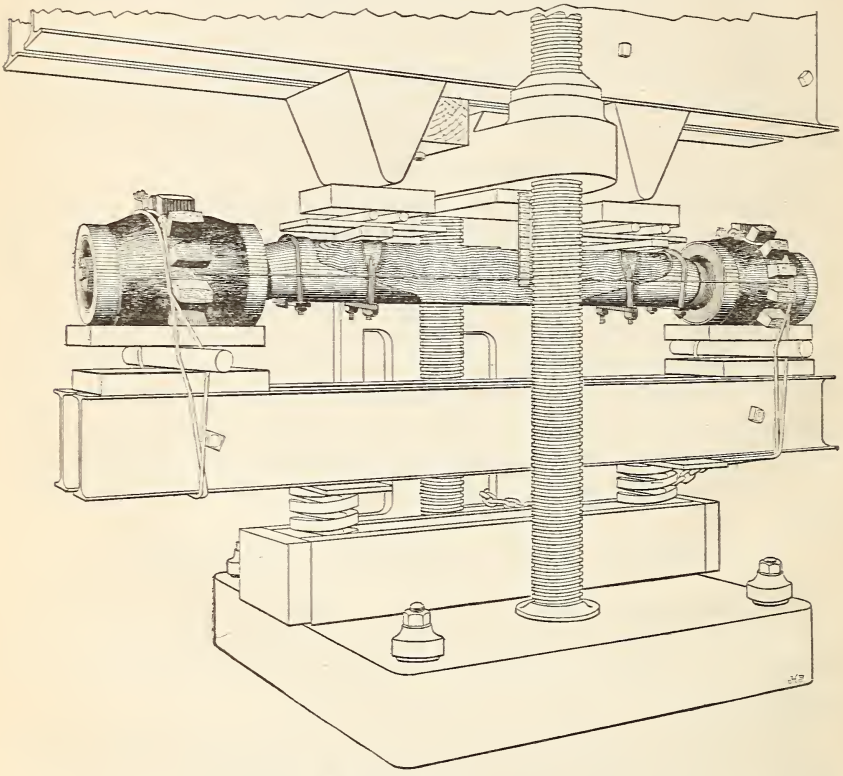

FIG. 6.—Method of testing wagon axles.

the maximum load in the maple axles was reduced so as to give the load that would be supported by maple axles of the same section as the hickory axles. In all three sets the maximum load carried by the maple axles was slightly greater than that carried by the hickory axles. The adjusted maximum load carried by the maple axles, however, is less than that carried by the hickory axles in the case of the thimble skein and the thimble skein trussed axles, and approximately the same in the case of the long-sleeve skein trussed axles. It is noticeable that the strength values are more constant in the hickory than in

the maple axles, which indicates a greater variation in the maple stock.

The amount of bending or deflection at maximum load was greater in the hickory axles than in the maple axles in all three sets, showing the greater toughness of hickory.

The hickory axles were able to stand a greater shock than the maple axles, as shown by the greater wheel drop-values. (See Table 3, Appendix.) The load supported after failure at maximum load was also much larger in the case of the hickory axles. When bending was

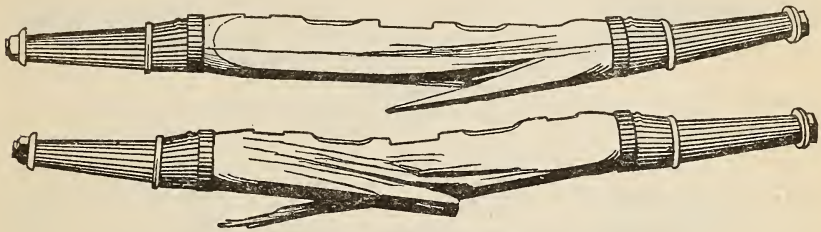

FIG. 7.—Maple wagon axles after test; thimble skein.

continued beyond the maximum load, the maple axles had little strength left in them to support a load. The hickory axles, on the contrary, carried a large per cent of their maximum load when subjected to the same conditions.

In the two sets of trussed axles the carrying capacity, ability to resist shock, and the load supported after failure at maximum load were all considerably increased over the same factors in the untrussed axles. In nearly every case the clamp and truss slipped while the axle was under test.

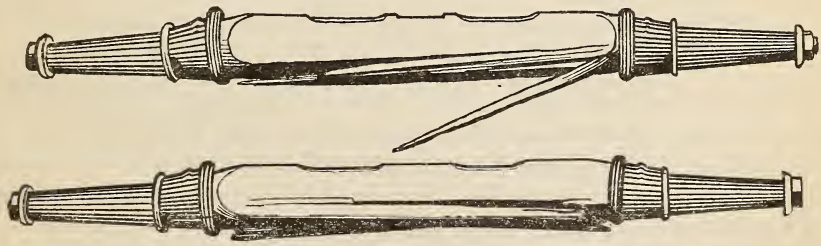

FIG. 8.—Hickory wagon axles after test; thimble skein.

In a number of axles received for test the manufacturers had allowed the shoulder on the ends of the truss to project beyond the clamp. This allows the axle to bend considerably before the truss shoulder is pulled against the clamp and the truss brought into action. Out of the 32 trussed axles, in only one instance did the truss rod break.

The character of the fractures in the tested axles is shown in figures 7–10. These figures were made from photographs of individual

axles taken after test. The maple untrussed axles, figure 7, generally failed near the center, showing a short fracture, while the failure in the hickory axles of the same design, figure 8, occurred near the skeins and showed a long, fibrous break.

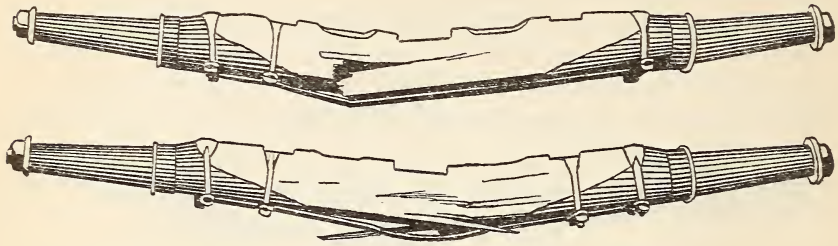

FIG. 9.—Maple wagon axles after test; long-sleeved skein trussed.

In the trussed axles, figures 9 and 10, the fractures were of the same general character, although less prominent. Maple is subject to a sort of spiral grain, whose presence is difficult of dectection, which sometimes causes sudden and complete failure.

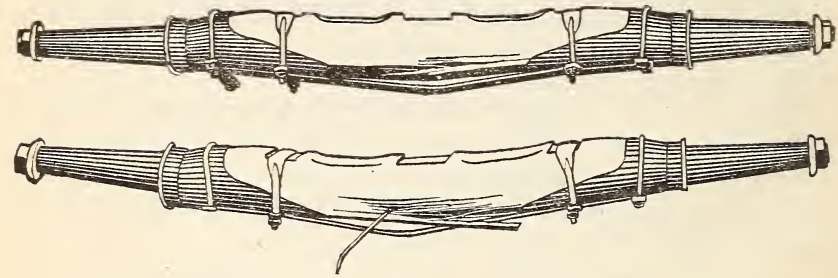

FIG. 10.—Hickory wagon axles after test; long-sleeved skein trussed.

TESTS ON OAK, SOUTHERN PINE, AND DOUGLAS FIR WAGON POLES.

The object of the wagon-pole tests was to check the correctness of the grading of select and common oak poles, to ascertain the utility of the truss, and to determine the value of southern pine and Douglas fir for pole manufacture, as compared with oak.

The poles tested were of the common farm-wagon design and were representative of the respective grades. The following comprised the series of tests:

10 oak poles, select grade.
10 oak poles, common grade.
10 oak poles, common grade, trussed.
10 southern pine poles.
10 Douglas fir poles.

The same dimensions prevailed in all the poles.

A device similar to the hounds on a wagon held the rear end of the pole rigid. (See fig. 11.) The point of the pole was deflected by means of a tackle and suitable rigging, which transferred the deflecting load to a platform scale, where it was measured. Thus the poles were tested to reproduce an action similar to that which occurs in service when the front wheels of a wagon are blocked and the team turns sidewise.

The results of the tests are given in Table 7 of the Appendix.

The select poles were superior to the common poles in strength, toughness, ability to resist shock, and stiffness by from 23 to 42 per cent. The poles appear to have been graded upon a correct mechanical basis.

The values for strength and stiffness were slightly higher in the case of the trussed poles. In toughness and shock-resisting ability,

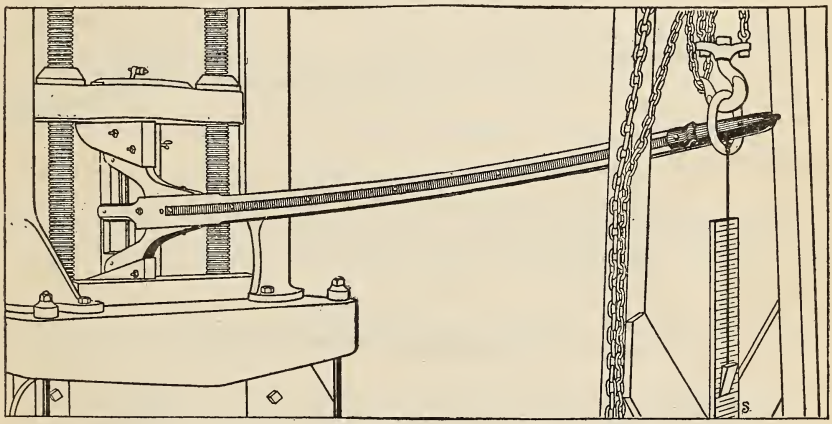

FIG. 11.—Method of testing wagon poles; trussed pole under test.

however, the reverse was the case. It is to be noted that more of the common untrussed poles were crossgrained than in the case of the common trussed poles. The truss does not appear to be of any decided value.

In maximum load and stiffness the pine poles rank between the oak select and oak common poles. In toughness and ability to resist shock the values for the pine poles are less than in either set of oak poles.

The fir poles were superior to the oak poles when not strained beyond the elastic limit. In strength and stiffness the fir ranked between the two grades of oak. The toughness and ability to resist shock was less in the fir poles than in the oak poles. The material in the fir poles was of a more uniform grade than in the oak or pine poles.

Figures 12 and 15 show typical failures in the poles under test.

The fractures in the select oak poles (see fig. 12) were longer and more fibrous than in the common oak poles. (See fig. 13.) A large

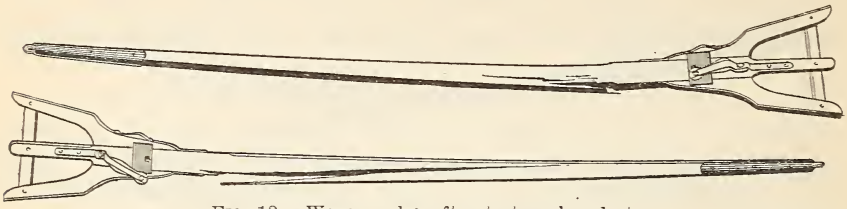

FIG. 12.—Wagon poles after test; oak, select.

number of the latter were crossgrained and had short beaks. In both grades of oak the fractures were generally localized near the hounds.

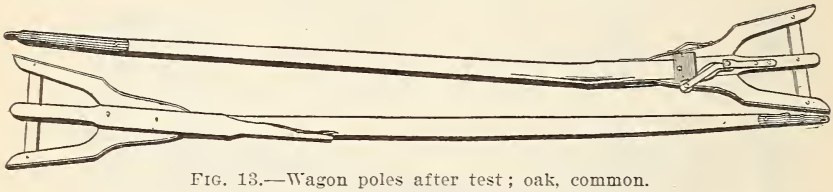

FIG. 13.—Wagon poles after test; oak, common.

The fractures in the southern pine poles (see fig. 14) were very long and splintery, extending the entire length of the pole in some cases.

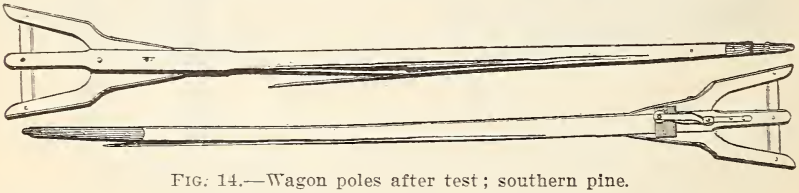

FIG. 14.—Wagon poles after test; southern pine.

The Douglas fir poles (see fig. 15) show fractures similar to those in the select oak poles. Seven out of 10 fir poles failed in compression in addition to the tension failure.

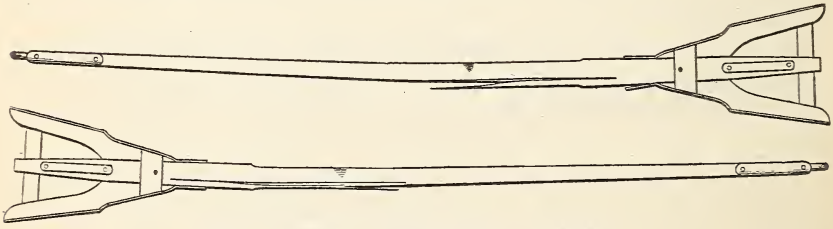

FIG. 15.—Wagon poles after test; Douglas fir.

TESTS ON DOUGLAS FIR AND SOUTHERN PINE CULTIVATOR POLES.

The object of the cultivator pole tests was to investigate the comparative value of Douglas fir and southern yellow pine for use in

cultivator pole manufacture. The material consisted of 10 Douglas fir and 10 southern pine cultivator poles of the kind used in walking cultivators. The method of testing was similar to that used in testing the wagon poles. (See fig. 11.)

Table 8 in the Appendix gives the results of the tests. There was little difference between the pine and fir poles for most of the quantities measured, but the range was much greater in the pine poles than in the fir poles. This indicates less variation of stock in the fir poles.

In the fir poles the load on the end of the pole at the elastic limit exceeded that for the pine poles by 5 per cent, while the strength of the fir poles at maximum load was 5 per cent less than that of the pine poles.

The pine poles were inferior to the fir poles in stiffness, but had a greater ability to resist shock.

In both sets of poles the majority of failures occurred near the point where the pole is attached to the framework of the cultivator. In the pine poles failure was complete in 7 out of 10, the poles breaking in two. In the fir poles complete failure occurred in but 3 out of 10.

CONCLUSIONS.

The foregoing tests, while in some cases only suggestive, because of the small number of samples tested, nevertheless show the value of laboratory tests in solving problems connected with the grading of vehicle wood stock, and the substitution of new species for old. The samples, representing different grades, or classes, were selected by experts with a large experience in the vehicle industries, and were thoroughly representative.

The spoke tests show an error of more than 50 per cent in the present grading system, which is largely due to the traditional prejudice and consequent discrimination against red hickory. No red spokes are now allowed in the A and B grades, yet these tests show that a large proportion of the red spokes now included in the lower grades should, because of their strength and toughness, be included in the highest grades.

The superiority of hickory in toughness and shock-resisting ability, as compared with maple, is brought out in the axle tests. It is probable that no native species has the mechanical properties possessed by the higher grades of hickory, which should on this account be saved for such parts as are subjected to the greatest stress. The shaft tests indicate that red oak may be substituted for hickory of the lower grades in shaft manufacture.

The difference in toughness between oak and such woods as southern pine and Douglas fir is shown in the results of the pole tests. Both of these latter species, however, when carefully selected, appear as promising substitutes for second-grade oak in pole manufacture.

The terms "second growth" and "forest growth" are so loosely applied in the designation of grades that they are confusing and might well be discontinued. These terms, as used by the trade, distinguish between good and poor wood and disregard the true meaning of the words. In order to use the terms in their correct sense the particular species and conditions of growth would have to be known for each piece of material. Commercially this is impossible. In reality a large per cent of the stock which is classed as "second growth" is "forest grown" stock of good quality. As changes in the forest take place, due to lumbering and new growth, it may be asked at what point does the wood cease to be "forest grown" and become "second growth." The manufacturer can not definitely answer this question and can not tell but what it is possible to secure both kinds of stock from the same tree. The term "black hickory" is also confusing when used to designate a grade, because it is the accepted common name for certain species.

There is much discrimination in the trade against defects, such as knots and checks, but little is said about crossgrain. The tests have continually shown that in such material as spokes, axles, and poles crossgrain is one of the most serious defects. Defects that will be removed in finishing should not be considered defects by the inspector. Clauses in grading rules such as "Clear of any defects impairing the strength" are too indefinite.

The most useful result of the vehicle-wood investigation is the placing of red hickory in its proper class. The real worth of red hickory, as shown by test and not by color, is a point that should not be lost sight of in grading hickory stock.

APPENDIX.

The following tables give the results of the tests on vehicle woods, with the exception of the spoke tests, which are given in Table 1, page 10. The various quantities measured in the tests are defined for the sake of clearness.

TABLE 2.—*Summary of tests on buggy shafts.*

Kind of wood.	Weight.	Per cent of moisture.	Specific gravity dry.	Load.		Deflection.		Fiber stress.		Work required to strain shafts to—			Stiffness factor.
				At elastic limit.	At maximum.	At elastic limit.	At maximum load.	At elastic limit.	At maximum load.	Elastic limit.	Maximum load.	After maximum load.	
	Lbs.			*Lbs.*	*Lbs.*			*Lbs.per sq. in.*	*Lbs.per sq. in.*	*In.-lbs.*	*In.-lbs.*		*Lbs.*
XX hickory:						*In.*	*In.*						
Average.....	4.22	10.9	.632	65	111	10.0	30.7	6,190	10,527	335	2,264	524	53
Maximum....	5.11	13.0	.754	101	153	14.0	44.0	9,620	14,180	650	3,620	2,176	76
Minimum....	3.32	9.9	.534	42	79	7.0	17.0	3,970	7,710	151	800	0	38
Red oak:													
Average.....	4.19	9.8	.627	70	122	9.9	28.4	6,474	11,318	348	2,256	295	57
Maximum....	4.57	10.8	.657	90	142	14.0	37.0	8,460	13,360	630	3,696	1,391	68
Minimum....	3.97	9.0	.597	56	100	7.0	23.0	4,640	8,130	203	1,408	0	42
RED OAK IN PER CENT OF XX HICKORY.													
	93.3	(a)	99.3	108	110	99	92.5	104.8	107.5	104	99.6	56.3	107.5

[a] The oak had 1.1 per cent less moisture than the hickory.

MEASURED QUANTITIES.

Weight of shaft in pounds.

Load at elastic limit in pounds, the greatest load that can be applied to the piece under test without destroying its ability to come back to its original shape when the load is removed.

Maximum load in pounds, the greatest load which the shaft can withstand.

Deflection at elastic limit and maximum load in inches, the movement of the point of the shaft required to bend it to the elastic limit and to the maximum load respectively.

COMPUTED QUANTITIES.

Per cent of moisture, the per cent of water in the shaft at the time of test.

Specific gravity (dry), the weight of the shaft when oven dry compared to the weight of an equal volume of water.

Fiber stress at elastic limit and at maximum load in pounds per square inch.

Work, in inch-pounds, done in straining a shaft to the elastic limit, to its maximum load, and the work done beyond the maximum load in straining the shaft to the end of the test. Work is a combination of force (average load) and distance through which the force acts (deflection of shaft). The work after maximum load is a measure of the toughness of a shaft, and shows the ability of a shaft to resist shock after there is a partial failure.

Stiffness factor, the load required to deflect the point of the shaft 8 inches.

TABLE 3.—*Summary of tests on maple and hickory wagon axles.*

Style of axle.	MAPLE. (Size 3¼″ x 10″–3¾″ x 4⅝″ rectangular part of axle.)								HICKORY. (Size 3¼″ x 10″ skein–3½″ x 4½″ rectangular part of axle.)							
	Load.		Deflection at hounds with reference to hubs.		Work required to strain axles to—		Drop of wheel (with 1 ton on axle) required to give work to maximum load.	Load on axle after failure at maximum load.	Load.		Deflection at hounds with reference to hubs.		Work required to strain axles to—		Drop of wheel (with 1 ton on axle) required to give work to maximum load.	Load on axle after failure at maximum load.
	Elastic limit.	Maximum load.	Elastic limit	Maximum load.	Elastic limit.	Maximum load.			Elastic limit.	Maximum load.	Elastic limit.	Maximum load.	Elastic limit.	Maximum load.		
Thimble skein:	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*	*Inch-tons.*	*Inch-tons.*	*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*	*Inch-tons.*	*Inch-tons.*	*Inches.*	*Pounds.*
Average	12,625	19,458	0.62	1.19	1.98	7.1	6.0	264	11,625	18,678	0.64	1.48	1.85	8.5	7.0	6,667
Maximum	14,000	24,100	.76	1.52	2.66	11.0	9.5	1,120	14,000	20,000	.80	2.03	2.45	11.0	9.0	11,850
Minimum	11,000	13,430	.50	.68	1.38	2.4	1.7	00	10,000	16,050	.56	1.23	1.40	6.9	5.7	510
Thimble skein trussed:																
Average	14,375	23,296	.68	1.37	2.49	9.6	8.2	5,779	12,250	21,414	.55	1.64	1.75	11.7	10.1	17,261
Maximum	17,000	26,890	.93	1.70	3.71	13.6	11.9	11,110	17,000	24,850	.85	2.40	3.61	16.6	14.4	20,570
Minimum	11,000	21,240	.50	1.18	1.38	7.2	6.0	00	9,000	19,350	.39	1.10	.88	7.4	6.1	14,280
Long-sleeve skein trussed:																
Average	13,375	22,601	.58	1.21	1.97	8.3	7.1	4,713	11,875	21,760	.55	1.69	1.68	11.7	10.0	11,463
Maximum	18,000	26,510	.73	1.60	3.29	12.9	11.3	15,230	14,000	24,240	.74	2.30	2.59	15.2	12.9	21,790
Minimum	11,000	17,450	.50	.77	1.37	3.6	2.8	00	9,000	19,030	.44	1.43	1.10	9.5	8.1	00

COMPARISON OF MAPLE AND HICKORY AXLES.

[Maple in per cent of hickory.]

Thimble skein	109	104	97	80	107	84	86	4	100	100	100	100	100	100	100	100
Thimble skein trussed	117	109	124	84	142	82	81	33	100	100	100	100	100	100	100	100
Long-sleeve skein trussed	113	104	105	72	117	71	71	41	100	100	100	100	100	100	100	100

COMPARISON OF TRUSSED AND UNTRUSSED AXLES.

[Trussed in per cent of untrussed.]

Thimble skein	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Thimble skein trussed	114	119	110	115	126	135	137	2,180	105	115	86	111	95	138	144	258
Long-sleeve skein trussed	106	116	94	102	99	117	118	1,780	102	116	87	114	91	138	143	172

Table 3 presents the average, maximum, and minimum values of the various quantities measured and computed in the tests for the three sets of axles. To indicate more clearly the relative value of the two species, and of the trussed and untrussed axles, the average values for the maple axles are expressed in per cent of the hickory, and those for the trussed axles in per cent of the untrussed axles.

The quantities in Table 3 listed under "load," "deflection," and "work" may be defined in the same general way as the corresponding quantities in Table 2 of the shaft tests. The drop of wheel (with 1 ton resting on axle) required to give work to maximum load is a combination of maximum load and deflection, and is a measure of the ability of the axle to absorb shock. This combination is represented by the distance through which a 1-ton weight would have to drop to strain the axle to its maximum load, or, what amounts to the same thing, the drop of the rear wheels with a load of 1 ton resting on the axle. The cushioning effect of the roadway and wheels is not taken into account. This quantity is useful in comparing the shock-resisting properties of the rear axles and not in estimating what height of drop a loaded axle would withstand in service.

The load on the axle after failure at maximum load is a measure of the life still left in the axle. This quantity was obtained by noting the load still held up by the axle after failure at maximum load had occurred.

TABLE 4.—*Strength of maple and hickory axles reduced to same size.*

Style of axle.	Maple.				Hickory.	
	Maximum load under test.	Maple in per cent of hickory.	Maximum load (adjusted to same section as hickory).	Maple in per cent of hickory.	Maximum load under test.	Hickory taken as 100 per cent.
Thimble skein:	*Pounds.*		*Pounds.*		*Pounds.*	
Average	19,458	104	16,600	89	18,678	100
Maximum	24,100	120	20,600	103	20,000	100
Minimum	13,430	84	11,500	72	16,050	100
Thimble skein trussed:						
Average	23,296	109	20,500	96	21,414	100
Maximum	26,890	108	23,700	96	24,850	100
Minimum	21,240	110	18,700	97	19,350	100
Long-sleeve skein trussed:						
Average	22,601	104	22,200	102	21,760	100
Maximum	26,510	109	26,000	107	24,240	100
Minimum	17,450	92	17,100	90	19,030	100

TABLE 5.—*Per cent of maximum load supported after failure in wagon axle tests.*

Maple.	Style of axle.	Hickory.
1	Thimble skein	36
25	Thimble skein trussed	81
21	Long-sleeve skein trussed	53

TABLE 6.—*Fiber stress of wood in wagon axles.*

	Maple.		Hickory.	
	Fiber stress in pounds per square inch at—		Fiber stress in pounds per square inch at—	
	Elastic limit.	Maximum load.	Elastic limit.	Maximum load.
Average	8,895	14,130	8,063	16,000
Maximum	9,950	17,600	9,150	17,100
Minimum	7,370	9,800	7,440	13,900

TABLE 7.—*Summary of tests on wagon poles.*

Kind of wood.	Weight.	Load.		End deflection.		Fiber stress.		Work required to strain poles to—		Stiffness factor.
		Elastic limit.	Maximum.	Elastic limit.	Maximum load.	Elastic limit.	Maximum load.	Elastic limit.	Maximum load.	
	Pounds.	*Lbs.*	*Lbs.*	*Inches.*	*Inches.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inch-pounds.*	*Inch-pounds.*	
Oak, select:										
Average	38.0	394	730	14.4	41.5	6,591	11,138	2,840	19,606	313
Maximum	40.0	550	882	18.0	50.0	9,150	13,670	4,950	28,500	522
Minimum	35.5	250	550	10.1	29.5	4,170	8,820	1,263	9,100	230
Oak, common:										
Average	35.8	337	564	14.8	32.0	5,650	8,897	2,490	11,450	241
Maximum	41.3	450	882	17.3	48.0	7,550	12,800	3,380	28,100	402
Minimum	33.8	240	412	10.1	17.8	3,990	6,950	1,212	3,850	143
Oak, common, trussed:										
Average		374	584	15.7	30.7	6,104	9,045	2,940	10,370	253
Maximum		460	765	20.0	42.0	7,700	11,850	3,750	14,850	365
Minimum		280	400	12.6	16.8	4,490	6,350	1,760	4,050	189
Southern pine:										
Average	34.0	439	644	15.5	26.3	7,034	10,000	3,400	9,255	289
Maximum	39.8	520	735	17.4	31.5	8,260	11,300	4,160	11,650	333
Minimum	32.0	320	492	12.5	23.0	5,070	7,710	2,160	6,000	223
Douglas fir:										
Average	33.6	467	608	16.6	27.3	7,136	9,027	3,880	9,735	270
Maximum	36.3	590	683	20.7	43.0	8,950	10,050	5,690	19,550	325
Minimum	28.3	415	520	15.0	21.0	6,100	7,660	3,230	5,900	220
PERCENTAGE COMPARISON OF WAGON POLES.										
Oak, select		100	100	100	100	100	100	100	100	100
Oak, common		86	77	103	77	86	80	88	58	77
Oak, common, trussed		95	80	109	74	93	81	103	53	81
Southern pine		112	88	108	63	107	90	120	47	92
Douglas fir		119	83	115	66	108	81	137	50	86

The quantities recorded in Table 7 may be defined in the same way as those recorded in Tables 2 and 3.

TABLE 8.—*Summary of tests on cultivator poles.*

Kind of wood.	Weight.	Load on end of pole.		End deflection.		Fiber stress.		Work required to strain poles to—		Stiffness factor.
		Elastic limit.	Maximum load.	Elastic limit.	Maximum load.	Elastic limit.	Maximum load.	Elastic limit.	Maximum load.	
	Pounds.	*Lbs.*	*Lbs.*	*Inches.*	*Inches*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Inch-pounds.*	*Inch-pounds.*	
Douglas fir:										
Average	20.1	305	391	14.9	20.6	9,362	11,782	2,277	4,872	220
Maximum	23.3	340	472	19.7	26.6	10,650	14,330	3,250	6,800	268
Minimum	16.5	230	308	11.7	13.0	6,810	9,650	1,580	2,240	164
Southern yellow pine:										
Average	20.6	289	413	15.9	26.1	8,535	11,682	2,300	6,654	192
Maximum	23.5	440	557	19.9	36.0	13,300	16,100	3,830	10,400	275
Minimum	15.5	160	200	11.9	13.5	4,740	5,930	952	1,640	127
DOUGLAS FIR IN PER CENT OF SOUTHERN YELLOW PINE.										
Southern yellow pine	100	100	100	100	100	100	100	100	100	100
Douglas fir	98	105	95	94	97	110	101	99	73	115

The quantities recorded in Table 8 may be defined in the same way as those recorded in Table 7.

Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *December 16, 1907.*

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